U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

CALiPER

Report 21.1:

Linear (T8) LED Lamps
in a 2×4 K12-Lensed Troffer

April 2014

Prepared for:

Solid-State Lighting Program
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Preface

The U.S. Department of Energy (DOE) CALiPER program has been purchasing and testing general illumination solid-state lighting (SSL) products since 2006. CALiPER relies on standardized photometric testing (following the Illuminating Engineering Society of North America [IES] approved method LM-79-08[1]) conducted by accredited, independent laboratories.[2] Results from CALiPER testing are available to the public via detailed reports for each product or through summary reports, which assemble data from several product tests and provide comparative analyses.[3] Increasingly, CALiPER investigations also rely on new test procedures that are not industry standards; these experiments provide data that is essential for understanding the most current issues facing the SSL industry.

It is not possible for CALiPER to test every SSL product on the market, especially given the rapidly growing variety of products and changing performance characteristics. Instead, CALiPER focuses on specific groups of products that are relevant to important issues being investigated. The products are selected with the intent of capturing the current state of the market at a given point in time, representing a broad range of performance characteristics. However, the selection does not represent a statistical sample of all available products in the identified group. All selected products are shown as currently available on the manufacturer's webpage at the time of purchase.

CALiPER purchases products through standard distribution channels, acting in a similar manner to a typical specifier. CALiPER does not accept or purchase samples directly from manufacturer's to ensure all tested products are representative of a typical manufacturing run and not hand-picked for superior performance. CALiPER cannot control for the age of products in the distribution system, or account for any differences in products that carry the same model number.

Selecting, purchasing, documenting, and testing products can take considerable time. Some products described in CALiPER reports may no longer be sold or may have been updated since the time of purchase. However, each CALiPER dataset represents a snapshot of product performance at a given time, with comparisons only between products that were available at the same time. Further, CALiPER reports seek to investigate market trends and performance relative to benchmarks, rather than as a measure of the suitability of any specific lamp model. Thus, the results should not be taken as a referendum on any product line or manufacturer. Especially given the rapid development cycle for LED products, specifiers and purchasers should always seek current information from manufacturers when evaluating products.

To provide further context, CALiPER test results may be compared to data from LED Lighting Facts,[4] ENERGY STAR® performance criteria,[5] technical requirements for the DesignLights Consortium® (DLC) Qualified Products

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1. IES LM-79-08, *Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*, covers LED-based SSL products with control electronics and heat sinks incorporated. For more information, visit http://www.iesna.org/.
2. CALiPER only uses independent testing laboratories with LM-79-08 accreditation that includes proficiency testing, such as that available through the National Voluntary Laboratory Accreditation Program (NVLAP).
3. CALiPER summary reports are available at http://www.ssl.energy.gov/reports.html. Detailed test reports for individual products can be obtained from http://www.ssl.energy.gov/search.html.
4. LED Lighting Facts® is a program of the U.S. Department of Energy that showcases LED products for general illumination from manufacturers who commit to testing products and reporting performance results according to industry standards. The DOE LED Lighting Facts program is separate from the Lighting Facts label required by the Federal Trade Commission (FTC). For more information, see http://www.lightingfacts.com.
5. ENERGY STAR is a federal program promoting energy efficiency. For more information, visit http://www.energystar.gov.

List (QPL),[6] or other established benchmarks. CALiPER also tries to purchase conventional (i.e., non-SSL) products for comparison, but because the primary focus is SSL, the program can only test a limited number.

It is important for buyers and specifiers to reduce risk by learning how to compare products and by considering every potential SSL purchase carefully. CALiPER test results are a valuable resource, providing photometric data for anonymously purchased products as well as objective analysis and comparative insights. However, photometric testing alone is not enough to fully characterize a product—quality, reliability, controllability, physical attributes, warranty, compatibility, and many other facets should also be considered carefully. In the end, the best product is the one that best meets the needs of the specific application.

For more information on the DOE SSL program, please visit http://www.ssl.energy.gov.

[6] The DesignLights Consortium Qualified Products List is used by member utilities and energy-efficiency programs to screen SSL products for rebate program eligibility. For more information, visit http://www.designlights.org/.

Outline of CALiPER Reports on Linear (T8) LED Lamps

This report is part of a series of investigations performed by the CALiPER program on linear LED lamps. Each report in the series covers the performance of up to 31 linear LED lamps, which were purchased in late 2012 or 2013. Summaries of the evaluations covered in each report are as follows:

Application Summary Report 21: Linear (T8) LED Lamps (March 2014)[7]
This report focused on the bare-lamp performance of 31 linear LED lamps intended as alternatives to T8 fluorescent lamps. Data obtained in accordance with IES LM-79-08 indicated that the mean efficacy of the group was slightly higher than that of fluorescent lamps (with ballast), but that lumen output was often lower. The color quality of the linear LED lamps varied substantially, with many of the products having worse color quality than a typical fluorescent T8 lamp (e.g., CRI less than 80). One important finding was the range in luminous intensity distribution, with clear-optic lamps all having a beam angle less than 120°, and diffuse-optic lamps all having a beam angle above 126°. None of the lamps had an omnidirectional luminous intensity distribution similar to that of a linear fluorescent lamp.

Report 21.1: Linear (T8) LED Lamps in a 2×4 K12-Lensed Troffer
This report focuses on the performance of the same 31 linear LED lamps operated in a typical troffer with a K12 prismatic lens. In general, luminaire efficacy is strongly dictated by lamp efficacy, but the optical system of the luminaire substantially reduces the differences between the luminous intensity distributions of the lamps. While the distributions in the luminaire are similar, the differences remain large enough that workplane illuminance uniformity may be reduced if linear LED lamps with a narrow distribution are used. At the same time, linear LED lamps with a narrower distribution result in slightly higher luminaire efficiency.

Report 21.2: Linear (T8) LED Lamp Performance in Five Types of Recessed Troffers (Pending)
Although troffers using a K12 lens are numerous, there are many other types of optical systems used with luminaires in which linear LED lamps could be installed. The report will look at the performance of three different linear LED lamps—chosen primarily based on their luminous intensity distribution—compared to a benchmark fluorescent lamp in five different troffer types.

Report 21.3: Cost-effectiveness of Linear (T8) LED Lamps (Pending)
Meeting performance expectations is important for driving adoption of linear LED lamps, but cost-effectiveness may be an overriding factor in many cases. Linear LED lamps cost more initially than fluorescent lamps, but energy and maintenance savings may mean that the life-cycle cost is lower.

In addition to these four technical reports, CALiPER will offer a concise guidance document that describes the findings of these studies and provides practical advice to manufacturers, specifiers, and consumers. As always, the applicability of general guidance to any specific application may vary. Further, the LED market is rapidly changing, meaning today's conclusions may or may not apply to products in the future. The performance and effectiveness of every lighting system should be evaluated on its own merits.

[7] Available at http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/caliper_21_t8.pdf

1 Background

The performance of LED T8 lamps outside a luminaire—referred to as bare lamps and analyzed in CALiPER Application Summary Report 21—is an important factor in determining the overall performance of an installed lighting system. However, luminaires also have a significant effect on light system performance, and there can be interactive effects between the lamp and luminaire, which may be less obvious. To investigate in-luminaire performance, CALiPER installed a pair of each of the Series 21 lamps in a typical 2×4 troffer with a K12-style prismatic lens, and then used absolute photometry to determine the combined system performance.

This report focuses on the attributes of the lamp-in-luminaire combinations, relating the measurements to the bare-lamp performance. In many cases, it is possible to establish relationships between bare-lamp performance parameters and total luminaire performance. For example, the luminaire efficiency of K12-lensed troffers is related to the optical system (and thus to the beam angle[8]) of the lamp installed, but luminaire efficacy is still highly correlated with lamp efficacy. That is, the effect of changed luminaire efficiency on total system efficacy is minimal, compared to differences in lamp efficacy.

Although for this report performance is evaluated using photometered values, one should not disregard the differences in appearance that can occur when different lamps are installed in a luminaire. For a K12-lensed troffer, this typically means that lamps with a narrower distribution (i.e., LED lamps with a clear lens and a beam angle less than 120°) appear more "stripey." That is, they have more contrast in the luminance pattern on the lens. While this may not substantially affect photometric performance, it may increase glare and affect judgments of quality.

Prismatic Lenses

A prismatic lens is perhaps the most basic and utilitarian optical system used with troffer luminaires. The lenses are often made of acrylic, and contain many small facets (prisms) that redirect the light that is incident on them. Prismatic lenses are used to shape the luminous intensity distribution of a luminaire into one that is more desirable than the emission from the lamps alone.

A K12 lens is a type of prismatic lens, with the designation referring to a specific pattern in the structure that is based on female conical prisms in a diagonal array. K12 lenses are commonly used in offices, schools, and commercial spaces, and are generally considered both economical and relatively efficient for a lensed system. A K12 lens redirects some light from high vertical angles (generally above 45°) to lower vertical angles (generally less than 45°). This can improve workplane uniformity and reduce glare.

Current and Future Performance of Linear LED Lamps

Relative to a fluorescent T8 lamp, the luminous intensity distributions of currently available linear LED lamps are all similar, as shown in Application Summary Report 21, with small differences based on the optical system. Importantly, the conclusions in this report (21.1) apply to those currently available linear LED lamps. As the products develop, novel distributions may be achieved, and it may even be possible to engineer a lamp's distribution so that it functions similarly to a fluorescent lamp in a specific type of troffer—or perhaps improvements in the distribution are possible. In many ways, the troffer luminaire is not the best fit for LED lighting; yet with the large installed troffer base, optimizing LED lamps for that type of system is important, especially for energy savings.

[8] Beam angle is defined as the angle between the two directions for which the intensity is 50% of the maximum intensity (ANSI/IES RP-16-10) or center beam intensity (ANSI C78.379-2006), as measured in a plane through the beam axis. It is most commonly used with directional lamps, but it has some utility for communicating the differences in luminous intensity distribution of the products included in this study.

2 Results

Linear LED lamps in K12-Lensed Troffer.

This report analyzes the independently tested performance of 31 linear LED products installed in pairs in a typical 2×4 K12-lensed troffer. Most of the lamps were anonymously purchased in the first half of 2013, with the remainder purchased in late 2012. In this report, they are referred to as the Series 21 products. Complete descriptions of each lamp type are available in Appendix A. Appendix B provides the specification sheet for the troffer.

It is acknowledged that the products included in this dataset may have been replaced with a newer model and/or may no longer be sold. However, that does not diminish the broader relevance of the findings. In fact, the lamps generally represent a snapshot of performance at the time of purchase,[9] and serve as an effective tool for comparing LED to benchmark technologies, while helping to illustrate some of the challenges of this specific application—challenges that are unlikely to abate in the near future. Further, the evaluation was not intended as a measure of the suitability of any specific lamp model, and the results should not be taken as a referendum on any product line or manufacturer.

One sample of each lamp-luminaire combination was tested according to IES LM-79-08 (absolute photometry), using a goniophotometer. The results are shown in Table 1. Because color quality is typically a property of the lamp, with the luminaire having little to no effect, it was not measured for the lamp-luminaire combination. Color quality data for the lamps can be found in Application Summary Report 21. This report focuses on the luminous intensity distribution of the samples, as well as overall output and efficacy.

Table 1. Results of CALiPER tests for the Series 21 linear LED lamps in a typical K12-lensed troffer. Spacing criterion values at 90° are perpendicular to (or "across") the long axis of the lamp. Both beam angle values are for the 90° plane (across the lamps). The *Labels* column indicates whether the product was qualified by the DesignLights Consortium (DLC) or listed by LED Lighting Facts (LF), based on searches of the respective product databases and/or manufacturer literature.

DOE CALiPER Test ID[1]	Initial Luminaire Output (lm)	Total Input Power (W)	Luminaire Efficacy (lm/W)	Luminaire Efficiency	Spacing Criterion (90°)	Beam Angle Bare (deg)	Beam Angle in Troffer (deg)	Labels	
T1-12-111	2,456	38.9	63	81%	1.26	129	101	-	-
T1-12-113	3,709	46.2	80	85%	1.20	113	94	DLC	LF
T1-12-114	3,190	37.4	85	81%	1.28	134	102	-	-
T1-12-115	2,418	31.8	76	80%	1.28	134	100	-	-
T1-13-01	2,853	35.1	81	85%	1.18	108	90	DLC	-
T1-13-03	2,701	36.4	74	84%	1.16	105	92	-	LF
T1-13-04	2,450	33.3	74	81%	1.28	144	99	-	LF

(continued on next page)

1. The "T1" in the CALiPER identification code indicates performance of the lamp in the K12-lensed troffer. Data for additional troffer types will be available in CALiPER Report 21.2. As is typical, the second set of digits indicates the year of purchase.

[9] While the products were purchased at the note time period, the date of manufacture may vary. CALiPER purchases products through standard distribution channels. The product model information is identified using manufacturer webpages and specification sheets. In some cases, "old" products are included because the model number was not changed after upgrades and/or stock remains in the distribution channel. This is a problem for all specifiers,

Table 1. (continued)

DOE CALiPER Test ID	Initial Luminaire Output (lm)	Total Input Power (W)	Luminaire Efficacy (lm/W)	Luminaire Efficiency	Spacing Criterion (90°)	Beam Angle Bare (deg)	Beam Angle in Troffer (deg)	Labels	
T1-13-05	2,728	35.0	78	85%	1.20	110	93	-	LF
T1-13-06	3,113	40.0	78	79%	1.30	135	103	DLC	-
T1-13-07	2,486	37.7	66	84%	1.20	111	92	-	-
T1-13-09	3,011	35.3	85	83%	1.26	142	103	-	-
T1-13-10	3,552	38.1	93	85%	1.20	114	92	DLC	-
T1-13-12	3,507	43.5	81	80%	1.24	130	101	DLC	-
T1-13-13	2,489	27.8	89	84%	1.22	114	93	-	LF
T1-13-14	3,410	34.6	99	85%	1.20	116	94	-	-
T1-13-15	2,374	32.4	73	79%	1.28	133	102	-	LF
T1-13-16	2,448	35.3	69	80%	1.26	138	101	-	-
T1-13-17	2,163	35.0	62	78%	1.32	159	105	-	-
T1-13-18	2,663	38.6	69	82%	1.28	131	101	-	LF
T1-13-19	2,510	36.7	68	80%	1.26	137	102	-	LF
T1-13-20	3,212	39.0	82	81%	1.30	148	103	-	-
T1-13-21	2,403	35.3	68	85%	1.24	120	95	-	-
T1-13-22	2,337	33.4	70	79%	1.30	143	103	-	-
T1-13-23	3,494	49.4	71	85%	1.18	105	91	DLC	-
T1-13-24	2,848	23.1	123	86%	1.22	120	97	DLC	LF
T1-13-25	2,138	40.1	53	79%	1.26	126	99	-	-
T1-13-26	2,749	37.1	74	79%	1.28	142	103	DLC	LF
T1-13-27	2,928	44.6	66	79%	1.26	133	101	-	-
T1-13-29	3,908	46.3	84	82%	1.38	152	106	DLC	-
T1-13-31	5,208	57.3	91	83%	1.22	114	94	DLC	-
T1-13-33	3,543	43.6	82	78%	1.30	151	101	DLC	LF
Minimum	2,138	23.1	53	78%	1.16	105	90	-	-
Mean	2,935	38.0	78	82%	1.25	129	98	-	-
Maximum	5,208	57.3	123	86%	1.38	159	106	-	-

DesignLights Consortium Qualified Products List Criteria

Linear LED lamps are not covered by the ENERGY STAR program, but are included on the DLC QPL. For DLC qualification, linear LED lamps must be tested alone and in a reference luminaire. The troffer used for this report is a qualified reference troffer for the DLC QPL. The performance criteria are as follows:

- Luminaire efficacy ≥ 85 lm/W
- Initial light output ≥ 3,000 lm
- Spacing criterion between 1.0 and 2.0 in both directions
- 75% of output in the 0–60° zone

- Lamp requirements:
    - CCT ≤ 5000 K
    - CRI ≥ 80
    - Power factor ≥ 0.90
    - THD ≤ 20%
    - Warranty ≥ 5 years

CALiPER Testing of Benchmark Fluorescent Troffers

To provide context to the measurements of the linear LED lamps in the K12-lensed troffer, CALiPER also photometered two F28T8 lamps in the same troffer. While CALiPER typically tests all benchmarks using absolute photometry, the data for this product configuration was calculated using the absolute photometry of the lamp-and-ballast combination along with a relative-photometry test of the lamps in the luminaire.[10] This provides a good approximation of an absolute photometry test. The results of this measurement are shown in Table 2, along with a past CALiPER test (absolute photometry) of two F40T12 lamps with magnetic ballast in a similar K12-lensed troffer. CALiPER does not have absolute photometry test data for F32T8 lamps in a K12-lensed troffer, but performance can be estimated, if desired, from the bare-lamp data provided in Application Summary Report 21.

Table 2. Results of CALiPER tests for the fluorescent benchmark lamps in typical K12-lensed troffers.

DOE CALiPER Test ID	Lamp Type	Initial Luminaire Output (lm)	Total Input Power (W)	Luminaire Efficacy (lm/W)	Luminaire Efficiency	Spacing Criterion (90°)	Beam Angle Bare (deg)	Beam Angle in Troffer (deg)
T-BK08-30[1]	F40T12	4,453	88	51	-[1]	1.38	Omni	104
T1-BK13-30[2]	F28T8	3,299	51	65	75%	1.40	Omni	107

1. Two Philips F40T12/SOFT WHITE/84/ lamps in Lithonia Lighting 49051 troffer (Prismatic lens), Universal Lighting Technologies 446-SLH-TC-P magnetic ballast (0.93 ballast factor).
2. Two GE F28T8XLSPX41ECO lamps in Columbia Lighting 4PS24-2 troffer (K12 prismatic lens), Philips Advance IOPA2P32N instant start electronic ballast (0.87 ballast factor).
3. Luminaire efficiency was not determined for this test.

[10] An absolute test of the lamp-luminaire system was approximated by multiplying the absolute photometry values for the bare-lamp system by the luminaire efficiency reported for the relative photometry test. Likewise, the luminous intensity distribution could be scaled by the ratio of the absolute photometry bare-lamp test lumens to the rated lumens used to scale the relative photometry file. This method accounts for thermal and optical effects in the same manner as absolute photometry, but eliminates the adjustment in total output made by the photometric laboratory when the relative photometry data was reported.

3 Analysis

Luminous Intensity Distribution

In comparing lamp performance with lamp-in-luminaire performance, several trends emerge. First, the K12 lens used for this testing dramatically diminishes the difference in luminous intensity distributions, both between the linear LED lamps and fluorescent T8, and between the different types of linear LED lamps. Figure 1 shows the bare-lamp (grey) and in-troffer (color) luminous intensity distribution for each product. Despite the variety of emission characteristics, operation in a K12-lensed troffer results in similar luminous intensity distributions for all products.

Figure 2 shows the same data, but only for the in-troffer measurements. In Figure 2, it is possible to see that there is still some separation between the performance of LED lamps with a clear lens (narrower beam angles) and LED lamps with a diffuse lens (wider beam angles). For all linear LED lamps except product 13-29, relatively less light is emitted between approximately 20° and 40°, compared to the fluorescent benchmark. Note that while the plot may suggest that the LEDs emit less light at all vertical angles, in fact they would emit more light straight down, given the same total lumen output.

Product 13-29 is notable for its ability to almost perfectly reproduce the luminous intensity distribution of the benchmark fluorescent troffer. To achieve this, it relied on a refractive aperture ("channeled optic") in combination with diffusion. Its different bare-lamp distribution also stands out; however, it does not have an atypical beam angle. This illustrates one of the substantial limitations with the beam angle metric.

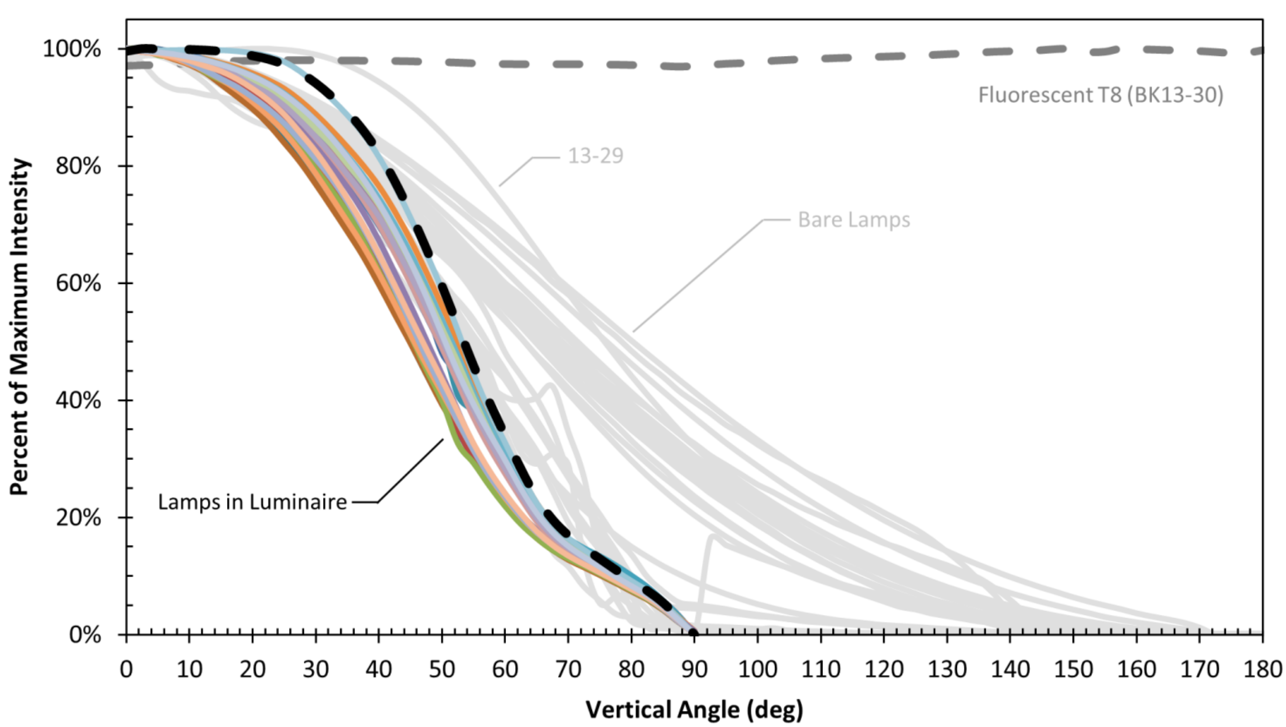


Figure 1. Relative luminous intensity in the 90° horizontal plane for each of the linear LED products and the fluorescent benchmark. The bare-lamp distribution for each lamp is shown in gray, whereas the in-luminaire distribution is shown in color.

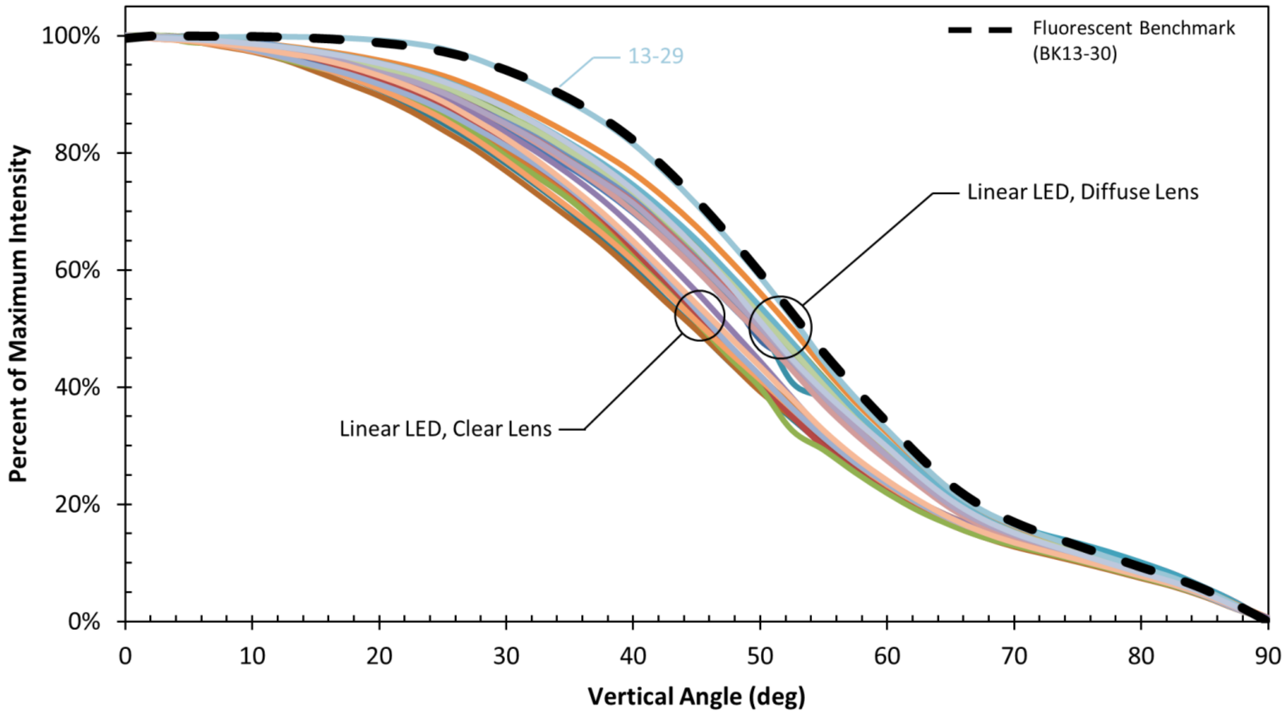


Figure 2. Relative luminous intensity of the 31 linear LED products tested and fluorescent benchmark BK13-30, all installed in the K12-lensed troffer. Despite a reduction in the product-to-product distribution variation, there remains some detectable difference between the LED lamps with a clear versus a diffuse optical system. The performance of all products is much closer to the benchmark than was measured for the bare lamps.

The compression of the distributions is further illustrated in Figure 3, which shows the change in beam angle for each product; that is, the beam angle of the bare lamp minus the beam angle of the lamp-luminaire combination, always in the 90° horizontal plane. While beam angle is not a metric typically used with recessed troffer lighting, it does help to illustrate the performance trends observed in this series of testing. Bare lamps with a wider beam angle (generally having a diffuse lens) were narrowed more than their counterparts with smaller bare-lamp beam angles (generally lamps with a clear lens). The conclusion that there is a linear translation between bare-lamp beam angle and luminaire beam angle is further reinforced by Figure 4, which shows the two variables having a linear regression coefficient of determination (R^2) of 0.84.

While the difference in the luminous intensity distribution of the luminaires may appear minimal, there is enough difference that performance may be altered. The across-the-lamp spacing criteria for the LED products ranged from 1.16 to 1.38, all of which were less than the spacing criterion of 1.40 for T1-BK13-30. With a ceiling height of 9' and a workplane height of 2.5', a luminaire with a spacing criterion of 1.4 would be optimized at 9.1' on center, whereas a luminaire with a spacing criterion of 1.16 would be optimized at 7.5' on center. Thus, if a fluorescent lamp was replaced with a narrow-beam LED lamp, the uniformity of the workplane might be reduced—depending on the spacing of the luminaires. For example, in the typical space described above, with luminaires spaced at 8' by 10' on center, T1-13-03 (spacing criterion of 1.16) would have a maximum-to-minimum illuminance uniformity ratio 16% greater than the fluorescent benchmark, T1-BK13-30.

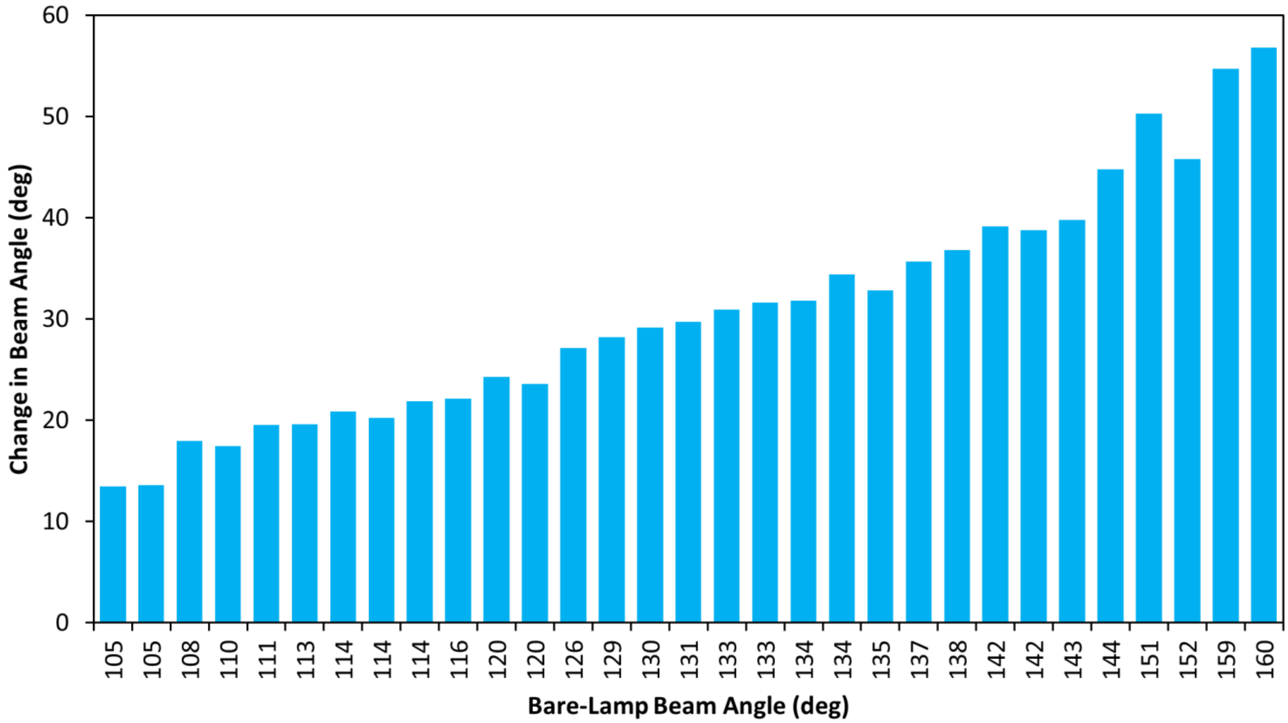


Figure 3. Change in measured horizontal beam angle (across the lamps) of the Series 21 linear LED products when the lamps were operated in a troffer versus operated alone. Although beam angle is not typically used with linear lamps or troffers, it helps to convey the performance, both alone and in-luminaire.

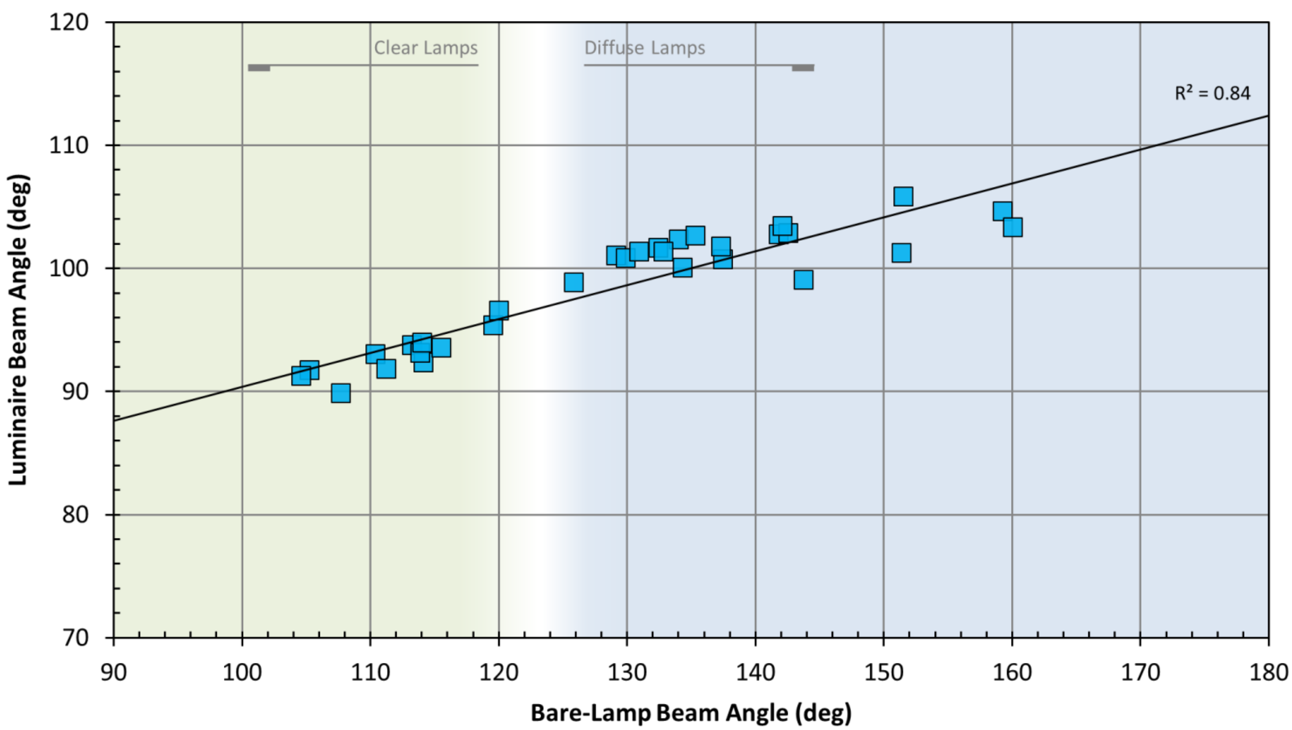


Figure 4. Luminaire beam angle versus bare-lamp beam angle (both across the lamps) for the Series 21 LED products. The two values are highly correlated—for K12-lensed luminaires and currently available linear LED lamps—indicating the absence of unpredictable interactions between the lamp and luminaire.

Luminaire Efficiency and Efficacy

Lamps with a narrower beam angle result in a higher luminaire efficiency, as shown in Figure 5. While there is a moderate linear correlation between luminaire efficiency and the beam angle of the lamp alone ($R^2 = 0.57$), differentiation between the clear lamps and diffuse lamps is perhaps more appropriate. Within each group, there was little correlation between luminaire efficiency and beam angle; that is, a clear lamp with a smaller beam angle would not be predicted to result in a higher efficiency than a clear lamp with a wider beam angle, for example. However, it can be concluded that clear lamps generally result in higher luminaire efficiency than diffuse lamps. In fact, there was no overlap between the groups, with the clear lamp resulting in the lowest troffer efficiency at 83.3%, and the diffuse lamp resulting in the highest troffer efficiency at 82.8%.

Another interesting outcome regarding luminaire efficiency was the performance of the benchmark fluorescent luminaire. As listed by the manufacturer, the troffer efficiency with two F32T8 lamps was measured at 86.5%. However, CALiPER measurements—performed by an independent photometric laboratory—determined the luminaire efficiency to be 75.2%. This discrepancy is important for interpreting the LED test data, as the higher, manufacturer-listed efficiency would indicate a decrease in luminaire efficiency when using linear LED lamps, but the lower, CALiPER-measured value indicates that the LED lamps resulted in higher luminaire efficiencies across the board. The CALiPER measurement was used for comparison in this report, and additional investigation of the difference was not within the scope of this report series.

Despite the modest differences in luminaire efficiency for clear and diffuse lamps, total luminaire efficacy is still predominantly a function of lamp efficacy—regardless of bare-lamp beam angle. This is illustrated in Figure 6, which documents the strong linear correlation between lamp efficacy and luminaire efficacy. Thus, if energy

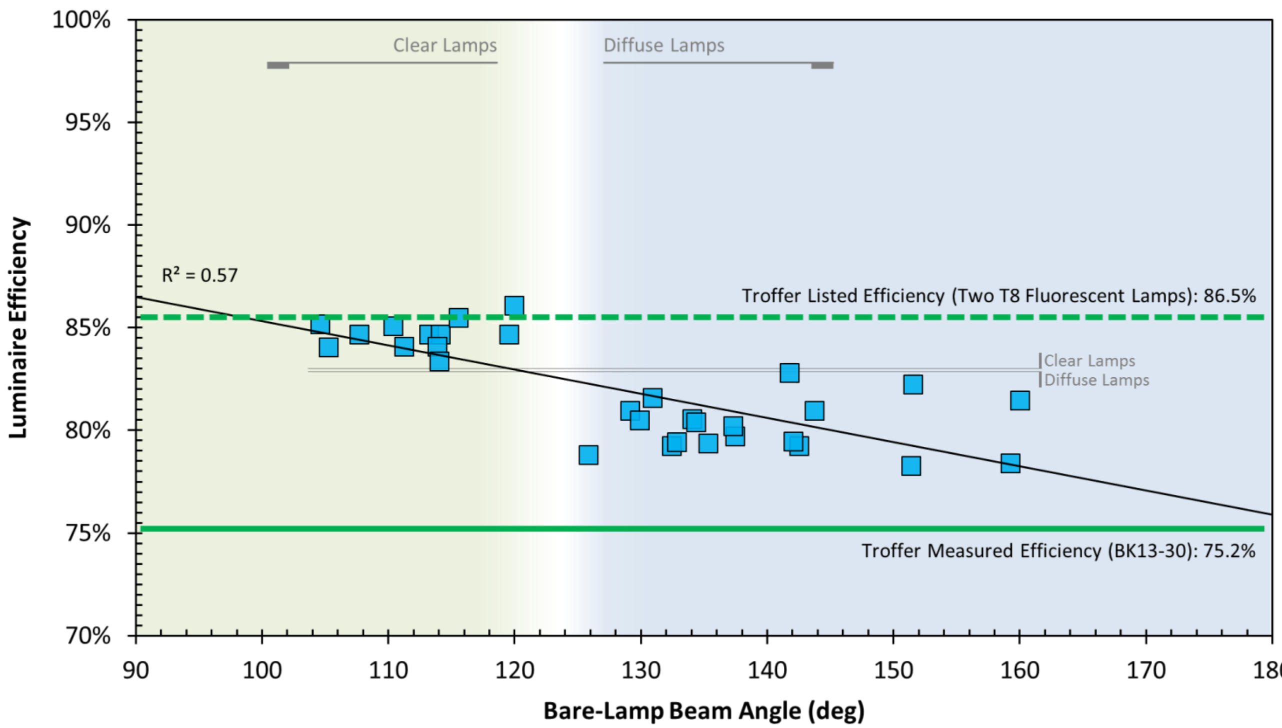


Figure 5. Luminaire efficiency versus bare-lamp beam angle. The efficiency of the K12-lensed troffer changes based on the lamp type installed; it was highest for LED lamps with a clear lens (narrow beam angles) and lowest with the fluorescent benchmark installed. The troffer manufacturer's data indicates a much higher efficiency for a comparable test, but this discrepancy was not investigated further by CALiPER.

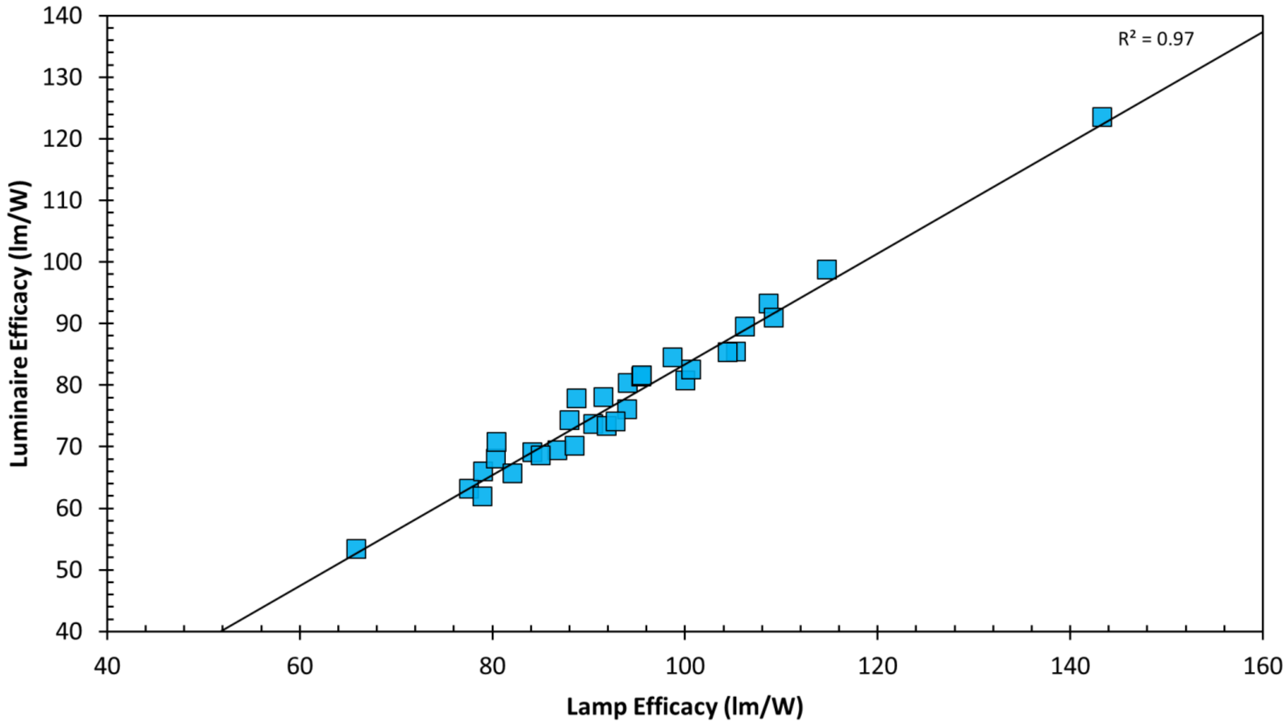


Figure 6. Luminaire efficacy versus lamp efficacy for the Series 21 linear LED products. Despite differences in luminaire efficiency based on the optical system/luminous intensity distribution of the LED lamps, luminaire efficacy is highly correlated with lamp efficacy. That is, the effect of differences in lamp efficacy cannot be overcome with improved luminaire efficiency.

efficiency is the primary concern, one should examine lamp efficacy first and consider the LED optical system (and resulting beam angle) a secondary factor. Further, due to appearance changes that are exacerbated by narrow-emitting linear LED lamps—and not necessarily reflected in the luminous intensity distribution—the minimal gains in luminaire efficiency may not outweigh the other outcomes (e.g., visual comfort).

Because there is a simple relationship, the scatterplot of luminaire efficacy and output for troffers (Figure 7) looks very similar to the scatterplot of lamp efficacy and output presented in Application Summary Report 21. The most notable difference is that fewer products meet the DLC QPL criteria for output and efficacy when installed in the troffer, versus bare-lamp performance. This is partially a result of the type of troffer used, since lensed troffers are often less efficient than those with other optical systems (e.g., parabolic louvers). The similarity of the plots is beneficial, in that it allows appropriate product selection using lamp performance—at least for K12-lensed troffers. That is, there are no unusual interactions that make certain lamps more effective in a K12-lensed troffer than others.

As with the bare lamps, the LED luminaires tended to emit less light than the fluorescent benchmark, T1-BK13-30. Only 8 of 31products emitted more light—with one product (T1-13-31) likely emitting too much light. As the older F40T12 (and magnetic ballast) benchmark demonstrates, less light from troffers has been a trend. There is no F32T8 shown, but it would likely fall in between T-BK08-30 and T1-BK13-30, given comparable quality—in fact, the range in efficacy of F32T8-based lighting systems is substantial. While the LED-lamped troffers tended to emit fewer lumens, they also almost all had higher efficacies than the fluorescent-lamped troffers. Thus, while reducing lumen output will save more energy, at the same output linear LED lamps are likely to save energy when installed in a K12-lensed troffer.

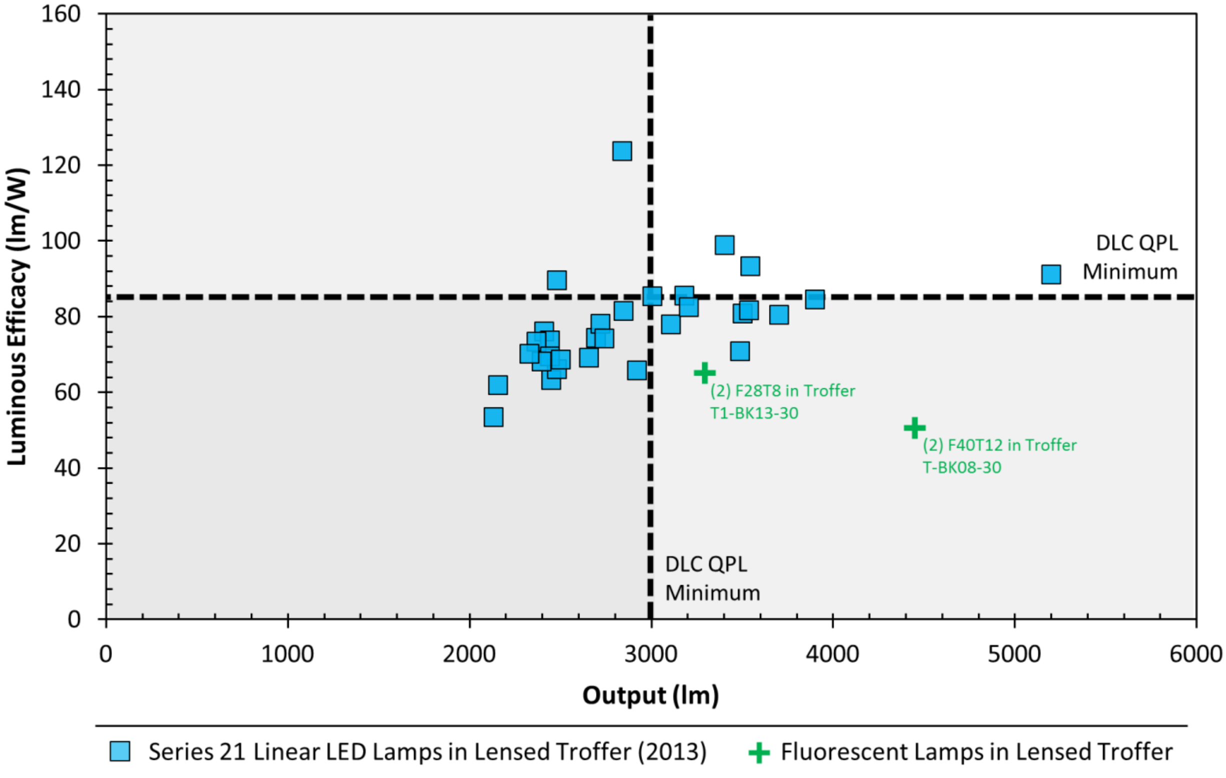


Figure 7. Efficacy and lumen output of the Series 21 linear LED lamps in a K12-Lensed Troffer versus fluorescent benchmarks in a similar troffer. Most of the LED lamp-and-luminaire combinations offered higher efficacy than the fluorescent-based systems, but many also provide lower lumen output.

Luminaire Appearance

While photometric performance comparisons are generally straightforward, comparisons of luminaire appearance, acceptability, and comfort are generally not. The results of this investigation indicate that K12-lensed troffers with linear LED lamps are generally more energy-efficient than the same troffers with T12 or T8 linear fluorescent lamps. Further, given the same lamp efficacy, system energy efficiency may be maximized by using lamps with narrow distributions (clear optics); however, those lamps may result in reduced illuminance uniformity on the workplane, because even in the K12-lensed troffer, the distribution is marginally narrower.

The data from this report cannot support any conclusions on the appearance, acceptability, or comfort of a lighting system using linear LED lamps versus one using linear fluorescent lamps. Given the different luminous intensity distributions of the lamps, it is likely that changes in appearance will occur, but the acceptability of those changes was not investigated. This open question is the subject of a pending report, CALiPER Report 21.2, which focuses on the photometric and subjective performance of three linear LED lamps from the broader sample of Series 21 LED lamps compared to the fluorescent lamp, all installed in five different troffer types—including a K12-lensed troffer.

4 Conclusions

As tested by CALiPER, the Series 21 linear LED lamps exhibited a range of performance—some good, some bad, but none truly similar to the performance of a linear fluorescent lamp across the board. Operating these linear LED lamps in a K12-lensed troffer greatly reduced the differences in luminous intensity distribution, with performance much more similar to that of the fluorescent benchmark.

While the lensed troffer reduced variation in luminous intensity distribution, it did not eliminate it; there was still some difference in performance that could be undesirable in a lighting installation. For instance, the lamps with a narrower distribution had a slightly smaller spacing criterion, which may result in uneven workplane illuminance. More important may be differences in luminaire appearance, although that aspect was not the subject of this report.

Linear LED lamps with a clear lens (narrower distribution) resulted in higher luminaire efficiency than the LED lamps with a diffuse optic (wider distribution), and all of the linear LED lamps resulted in higher luminaire efficiency than the fluorescent benchmark. The marginal gains in efficiency for narrow-beam lamps cannot overcome broader differences in lamp efficacy, however. Thus, in choosing a lamp for energy savings, lamp efficacy should be the primary consideration. Luminous intensity distribution may be a secondary consideration, with clear lamps providing slightly higher luminaire efficiency but also potentially resulting in lower workplane illuminance uniformity.

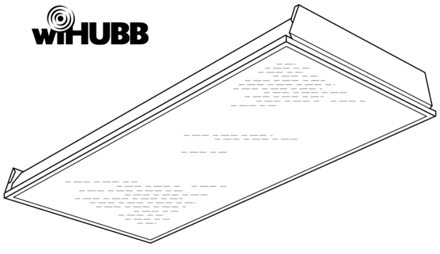
Overall, many of the tested linear LED lamps provided higher luminaire efficacy in a K12-lensed troffer. About one-third of the products provided lumen output approximately equivalent to that of a fluorescent system with the same number of lamps, with one providing too much lumen output and the remainder providing lower lumen output. Lowering the output of a troffer system is one way to save energy, but that can also be accomplished just by using lower-output fluorescent lamps, or lower ballast-factor ballasts, or both.

On average, the LED-lamped, K12-lensed troffers were approximately 25% more efficacious than the BK13-30 electronically ballasted F28T8 fluorescent benchmark, with some much higher and others barely providing any energy savings. Given the disparity in cost between LED and fluorescent systems, the financial benefit and long-term cost savings associated with LED retrofits should be considered on a case-by-case basis.

Columbia
LIGHTING

4PS24-2, 4PS24-3

2' × 4' Specification Grade Static Troffer / 2 or 3-Lamp T5, T5HO, T8



Also available with 4 or 6 lamps.

PROJECT INFORMATION

Project Name ____________________ Type ________

Catalog No. ____________________ Date ________

FEATURES

- 4¼" deep fluorescent troffer eliminates lens shadowing
- Lamp-to-lens spacing is over 2"
- Contoured housing maximizes photometric performance with uniform lens brightness
- Mitered corners on door present a clean uninterrupted appearance
- Rolled edge housing on all four sides makes the fixture safer and easier to handle
- Heavy duty door frame enhances appearance from eye level
- Snug door fit eliminates light leaks
- Recessed, surface or cable mount
- UL listed 1598
- Available with exclusive wiHUBB technology preinstalled
  – Peer to peer, self-healing wireless mesh network
  – Integrated control system for 0-10VDC or step dimming, or On/Off

CONSTRUCTION

Housing is constructed of heavy gauge steel, die formed for extra rigidity. Standard flush door is formed steel with mitered corners. Doors are retained by cam action latches, are easily removed without tools, and hinge from either side. Regressed or flush aluminum doors with mitered corners are also available. End caps are hinged and screwed to the housing for extra rigidity. Four integral T-bar clips are located in the end caps. Wireway accessible from below for upgrades or maintenance.

BALLAST & ELECTRICAL

All luminaires are completely wired with class "P," thermally protected, resetting, HPF ballast, sound rated A. Lampholders are medium bi-pin with positive retention. Furnished with an access plate. CEE NEMA Premium compliant.

FINISH

All metal parts processed with a multi-stage phosphate bonding treatment and finished with a high reflectance baked white enamel. For a post painted housing finish suffix catalog number with PAF.

SHIELDING

Standard lens is a 100% prismatic virgin pattern 12. Other shielding may be specified. If desired shielding media is not shown in ordering guide, contact your local Hubbell Lighting representative.

CEILING COMPATIBILITY

Designed for recessed installation in standard inverted tee grid ceilings (G), recessed installation in hard ceilings (G with FK accessory), Surface mount at ceiling plane (SM) or cable mount suspension below ceiling plane (CM). For compatibility with specific ceilings contact your Hubbell Lighting representative.

CERTIFICATION

All luminaires are built to UL 1598 standards and bear appropriate UL and cUL or CSA labels. Damp location labeling is standard. Emergency-equipped fixtures labeled UL 924.

ORDERING INFORMATION

EXAMPLE **4PS24-332G-FSA12-EU-SLL**

4PS 24 – ___ ___ ___ – ___ ___ – ___ ___ – ___

MODEL

4PS	Specification Grade Static Troffer

SIZE

24	2' × 4'

NO. OF LAMPS

2	Two
3	Three

LAMP TYPE

28	4', T5: 28 Watt
32	4', T8: 32, 30, 28 or 25 Watt
54	4', T5HO: 54 or 51 Watt

CEILING TYPE

G	Inverted T-bar (std.)
F	Overlap Flange (4½" overall fixture height)
M	Fit-in Flange (4½" overall fixture height)
SM	Surface Mount
CM	Cable Mount[1]

DOOR STYLE

FS	Flush Steel
FA	Flush Aluminum
RA	Regressed Aluminum
SFA	Silver Flush Aluminum
SRA	Silver Regressed Aluminum

SHIELDING

A12	Acrylic Prismatic Pattern 12
A15	Acrylic Prismatic Pattern 15
A19	Acrylic Prismatic Pattern 19
PC1	½" × ½" × ½" Specular Silver Polystyrene Louver
PC2	1½" × 1½" × 1" Specular Silver Polystyrene Louver

For thicker lens, specify - Example: A12125

VOLTAGE

U	120V-277V
347	347V

BALLAST

E	Electronic T8, Instant Start
ELW	2-Lamp Electronic T8, 0.77 Ballast Factor, Low Wattage, Instant Start
3E	3-Lamp Electronic T8, Instant Start
3ELW	3-Lamp Electronic T8, 0.77 Ballast Factor, Low Wattage, Instant Start
EP	Electronic T5 or T8, Programmed Start
3EP	3-Lamp Electronic T5HO or T8, Programmed Start

For specific ballast vendor, show as option.

OPTIONS

F0735	35K 75 CRI T8 Lamps Installed
F0835	35K 80CRI T8 Lamps Installed
F5835	35K 80CRI T5 Lamps Installed
GLR	Fast Blow Fuse
EL	Emergency Battery Pack
EL5	Emergency Battery Pack, T5 or T5HO
PAF	Paint After Fabrication
SLL	Spring Loaded Latches
MS9	Master/Satellite Pair w/9' Harness
NYC	NYC Compliant
NYCU	NYC Compliant, Union Label
WIH	wiHUBB Enabled[2,3]
EOR	End of Row (SM or CM only)[4]
INT	Intermediate (SM or CM only)[4]

ACCESSORIES (ORDER SEPARATELY)

CM48Y2SC3F-KIT	48" Cable Mount Kit for 2' Wide CM ceiling type, 3 Wire Feed Cord

[1] Order hanger accessories separately.
[2] Not available with Surface Mount Ceiling Types.
[3] In-Fixture Module Antenna adds 2" to overall fixture height at power feed location.
[4] Provides end wiring access for continuous row mounting. Contact factory for 3-lamp configurations.

4PS24-2, 4PS24-3

2' × 4' Specification Grade Static Troffer / 2 or 3-Lamp T5, T5HO, T8

PHOTOMETRIC DATA

Test **14272** Test Date **4/4/06**

LUMINAIRE DATA

Luminaire	**4PS24-232G-FSA12 4PS Lensed Troffer 2' × 4' 2-Lamp White Troffer with Prismatic A12 Acrylic Lens**
Ballast	**REL-2P32-SC**
Ballast Factor	**0.88**
Lamp	**F32T8**
Lumens per Lamp	**2900**
Total Input Watts	**64**
Mounting	**Recessed**
Shielding Angle	**0° = 90 90° = 90**
Spacing Criterion	**0° = 1.22 90° = 1.34**
Luminous Opening in Feet	**Length: 3.81 Width: 1.81 Height: 0.00**

AVG. LUMINANCE (Candela/Sq. M.)

Average Luminance Angle	0.0	22.5	45.0	67.5	90.0
0	3161	3161	3161	3161	3161
30	3010	3093	3246	3311	3340
40	2765	2836	3007	3132	3197
45	2558	2574	2733	2865	2956
50	2263	2292	2419	2542	2610
55	1992	1989	2068	2158	2242
60	1761	1617	1664	1751	1929
65	1592	1326	1285	1418	1655
70	1524	1273	1141	1323	1538
75	1550	1357	1345	1369	1574
80	1573	1519	1591	1519	1591
85	1755	1701	1773	1684	1701

ZONAL LUMEN SUMMARY

Zone	Lumens	% Lamp	% Fixt.
0-30	1613	27.8	32.1
0-40	2640	45.5	52.6
0-60	4280	73.8	85.3
0-90	5018	86.5	100.0
0-180	5018	86.5	100.0

COEFFICIENTS OF UTILIZATION (%)

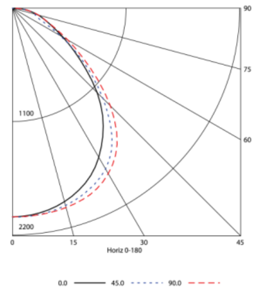
RC	80				70				50			0
RW	70	50	30	10	70	50	30	10	50	30	10	0
RCR 1	91	88	84	93	89	86	83	85	83	80	67	74
2	80	75	70	85	79	74	70	76	72	68	57	63
3	71	65	60	78	70	64	59	68	62	58	49	54
4	64	57	51	72	63	56	51	61	55	50	42	47
5	58	50	45	66	57	50	45	55	49	44	37	41
6	52	45	39	61	51	44	39	50	44	39	32	37
7	47	40	35	57	47	40	35	45	39	35	28	33
8	43	36	32	53	43	36	31	42	36	31	25	29
9	40	33	28	50	39	33	28	39	32	28	23	26
10	37	30	26	47	37	30	26	36	30	26	21	24

RCR = Room Cavity Ratio
RC = Effective Ceiling Cavity Reflectance **RW** = Wall Reflectance

ENERGY DATA

Total Luminaire Efficiency	**86.5%**
Luminaire Efficacy Rating (LER)	**69**
IESNA RP-1-1993 Compliance	**Noncompliant**
Comparative Yearly Lighting Energy Cost per 1000 Lumens	**$3.48 based on 3000 hrs. and $0.08 per KWH**

INDOOR CANDELA PLOT



Test **14271** Test Date **4/3/06**

LUMINAIRE DATA

Luminaire	**4PS24-332G-FSA12 4PS Lensed Troffer 2 × 4 3-lamp white troffer with prismatic A12 acrylic lens.**
Ballast	**REL-3P32-SC**
Ballast Factor	**0.88**
Lamp	**FO32T8**
Lumens per Lamp	**2900**
Total Input Watts	**87**
Shielding Angle	**0°=90 90°=90**
Spacing Criterion	**0° = 1.24 90° = 1.31**
Luminous Opening in Feet	**Length: 3.81 Width: 1.81 Height: 0.00**

AVG. LUMINANCE (Candela/Sq. M.)

Average Luminance Angle	0.0	22.5	45.0	67.5	90.0
0	4516	4516	4516	4516	4516
30	4354	4445	4569	4643	4655
40	4055	4140	4287	4411	4503
45	3766	3836	4009	4161	4271
50	3400	3480	3640	3803	3878
55	3070	3129	3236	3451	3459
60	2753	2710	2747	3022	3084
65	2415	2212	2168	2493	2619
70	2191	1812	1702	2104	2355
75	2117	1737	1622	2008	2388
80	2256	1924	1933	2202	2481
85	2275	2149	2203	2525	2454

ZONAL LUMEN SUMMARY

Zone	Lumens	% Lamp	% Fixt.
0-30	2297	26.4	31.3
0-40	3754	43.1	51.1
0-60	6226	71.6	84.8
0-90	7343	84.4	100.0
0-180	7343	84.4	100.0

COEFFICIENTS OF UTILIZATION (%)

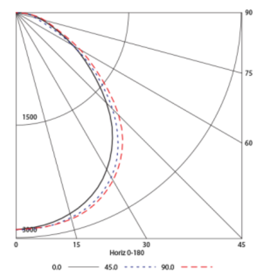
RC	80				70				50			0
RW	70	50	30	10	70	50	30	10	50	30	10	0
RCR 1	92	89	85	82	90	87	84	81	83	81	78	72
2	85	78	73	68	83	77	72	68	74	70	66	61
3	78	69	63	58	76	68	62	57	66	60	56	53
4	72	62	55	50	70	61	54	49	59	53	49	46
5	66	56	48	43	64	55	48	43	53	47	42	40
6	61	50	43	38	60	50	43	38	48	42	37	35
7	57	46	39	34	55	45	38	34	44	38	33	31
8	53	42	35	30	52	41	35	30	40	34	30	28
9	50	39	32	27	48	38	32	27	37	31	27	25
10	46	36	29	25	45	35	29	25	34	29	25	23

RCR = Room Cavity Ratio
RC = Effective Ceiling Cavity Reflectance **RW** = Wall Reflectance

ENERGY DATA

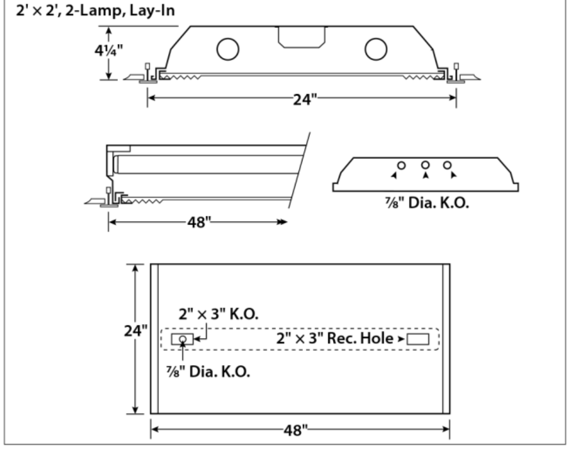
Total Luminaire Efficiency	**84.4%**
Luminaire Efficacy Rating (LER)	**72**
IESNA RP-1-1993 Compliance	**Noncompliant**
Comparative Yearly Lighting Energy Cost per 1000 Lumens	**$3.33 based on 3000 hrs. and $0.08 per KWH**

INDOOR CANDELA PLOT

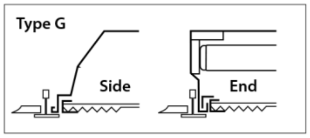


DIMENSIONAL DATA

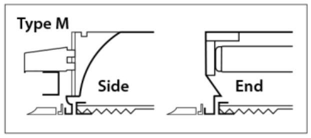
2' × 2', 2-Lamp, Lay-In



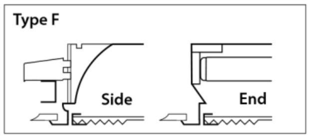
CEILING COMPATIBILITY



For lay-in installation in exposed grid ceilings. Maximum tee widths of 1" and maximum tee heights of 1½" allowed.



"Fit-in" style extruded trim aligns with modular tile joint. Fixture is supported from concealed suspension, includes adjustable wing hangers. 4½" overall fixture height.

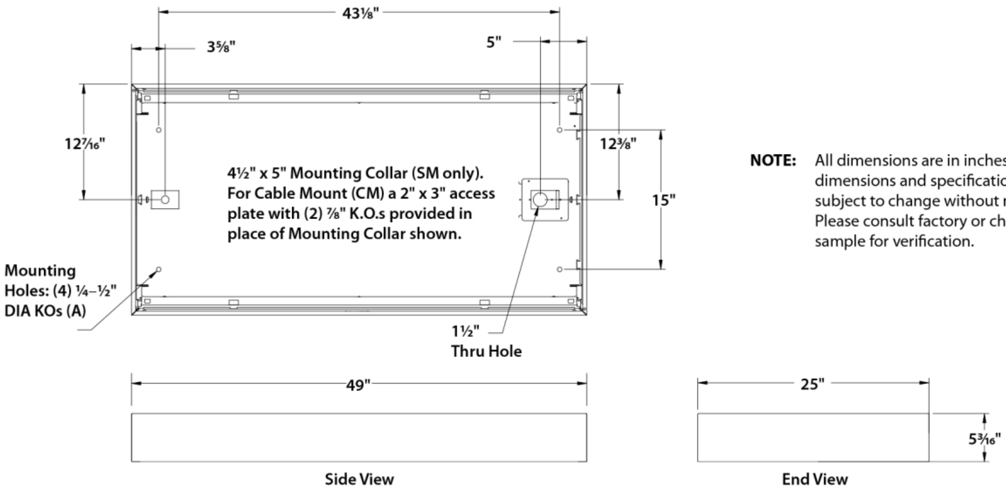


Overlapping trim conceals edges of ceiling opening. Wing hanger suspension included. 4½" overall fixture height.

Flanged cut out dimension for single unit only: 24⅛" × 48⅛"

NOTE: All dimensions are in inches; dimensions and specifications are subject to change without notice. Please consult factory or check sample for verification.

DIMENSIONAL DATA - SURFACE MOUNT (SM) OR CABLE MOUNT (CM)



NOTE: All dimensions are in inches; dimensions and specifications are subject to change without notice. Please consult factory or check sample for verification.

SURFACE MOUNT

Order SM ceiling type. Mounting collar required for surface mounting. (4) Mounting knock-outs, ¼" to ½" provided as shown, marked "A".

CABLE MOUNT

Order CM ceiling type. Access plate supplied for cable mounting or suspension. Use CM48Y2C3F-KIT 48" cable mount kit. Includes 3 wire feed cord. For other wiring needs, contact Hubbell Lighting representative. Mounting knock-outs, ¼" to ½", provided as shown, marked "A".

Appendix B: Product Identification

Table B1. Product brand and model identification for the tested LED lamps.

DOE CALiPER Test ID	Brand	Model
12-111	OSRAM Sylvania	LED22T8L48/841/120/120-277V
12-113	RedBird LED	L4-22W-41K-132
12-114	Ohyama	LDFL2000NF-H50KNA
12-115	Clean Light Green Light	CLGL-17-342SMDS
13-01	Aleddra	LLT-4-T8-C-SW-120-110V
13-03	Toggled	MK2M-T8-48-UN19ND-4080D2-A1
13-04	American Lighting	LT8-4841-PRO
13-05	Borealis Lighting	LEDT8C-4100K-4-277V
13-06	Kumho	FL/T8-32W/22W IU-841
13-07	Advanced Control Technology	SA4120W-4500K
13-09	GoLED	L8LT84FT4500KFR18W120 LED
13-10	LED Lighting Services	LLI-T8HLO-4-4500-C-B-P2
13-12	Zytech	ZYLEDT8-12S-23
13-13	eLED	LEDFLT8-NW48-BIPARV
13-14	Enervation	EL-T8-048-288.DIP(WW)
13-15	Lumena	TB-T8-120017W-42
13-16	Lighting Solutions Group	LED-T8-48-22-NW-FR
13-17	Vivid LEDs	VVD3002-N-UNV-DM (HFL-8060N-120601-L3)
13-18	Philips	19T8/END/48-4000 UNV (421875)
13-19	SeeSmart	200204 (Tube Light, 4 foot, 19W, NWM, 120-277V, SEP, HP)
13-20	Miracle LED	T8 Cool 48"
13-21	Eco-$mart	ECO-A-4G5 (HFL-8060N-120601-L3)
13-22	Luxant LED Lighting	BT8-4/18NX1F (A0001TL018F40E)
13-23	Next Lighting	NL48-UNV2-22-840-00 (NL48-22-840-00-001)
13-24	Sunritek	ST-PT12-02
13-25	LED Smart	ALB-T10-G13-48-24-C-S-S
13-26	Green Illuminating Systems	GIS-19T8/42120 (FP-19T8/42120)
13-27	InnoGreen	IG-220DT8120-20-NW
13-29	Independence LED Lighting	T-42940K-70-CB2
13-31	Philips Lighting	22T8/EXT/48-4000K UNV (427203)
13-33	Cree	UR2-48-45L-40K-S-FD
BK13-30	Lamp: GE Ballast: Philips Advance	F28T8XLSPX41ECO IOPA2P32N

Appendix C: Product Characteristics

Table C1. Physical and electrical characteristics of the Series 21 LED products.

DOE CALiPER Test ID	Optics	Rotatable	External Driver	Requires Unshunted Sockets	Wiring Location	Configuration Type[1]
12-111	Diffuse	No	No	Yes	Both Ends, Connector	C
12-113	Clear	No	No	Yes	One End	A
12-114	Diffuse	No	No	No	Both Ends	B
12-115	Diffuse	Yes	No	No	Both Ends	B
13-01	Clear	No	No	No	Both Ends	B
13-03	Clear[2]	No	No	Yes	One End	A
13-04	Diffuse	No	No	Yes	One End	A
13-05	Clear	No	No	Yes	One End	A
13-06	Diffuse	No	No	No	Both Ends (Ballast)	F
13-07	Clear	No	No	No	Both Ends	B
13-09	Diffuse	Yes	No	Yes	One End	A
13-10	Clear	No	No	No	Both Ends	B
13-12	Diffuse	No	No	Yes	One End	A
13-13	Clear[3]	Yes	No	Yes	One End	A
13-14	Clear	Yes	No	No	Multiple	(A)
13-15	Diffuse	Yes	No	No	Multiple	(C)
13-16	Diffuse	No	No	No	Multiple	(B)
13-17	Diffuse	No	Yes	No	Both Ends	E
13-18	Diffuse	No	No	Yes	One End	A
13-19	Diffuse	No	No	Yes	One End	A
13-20	Diffuse	No	No	Yes	One End	A
13-21	Clear	No	Yes	No	Both Ends	E
13-22	Diffuse	No	Yes	Yes	One End	D
13-23	Other	No	Yes	No	Both Ends	E
13-24	Clear	No	No	Yes	One End	A
13-25	Diffuse	No	No	No	Both Ends	B
13-26	Diffuse	No	No	Yes	One End	A
13-27	Diffuse	No	No	Yes	One End	A
13-29	Diffuse[4]	No	Yes	No	Both Ends	E
13-31	Clear	No	Yes	No Power	One End	G
13-33	Diffuse	No	Yes	No Sockets	One End	G

1. Configuration type corresponds with the wiring diagrams shown in Appendix F.
2. Lightly frosted.
3. Refractive lens.
4. In addition to diffusion, the product included a “channeled optic” to refract light.

DOE SSL Commercially Available LED Product Evaluation and Reporting Program
NO COMMERCIAL USE POLICY

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BUILDING TECHNOLOGIES OFFICE